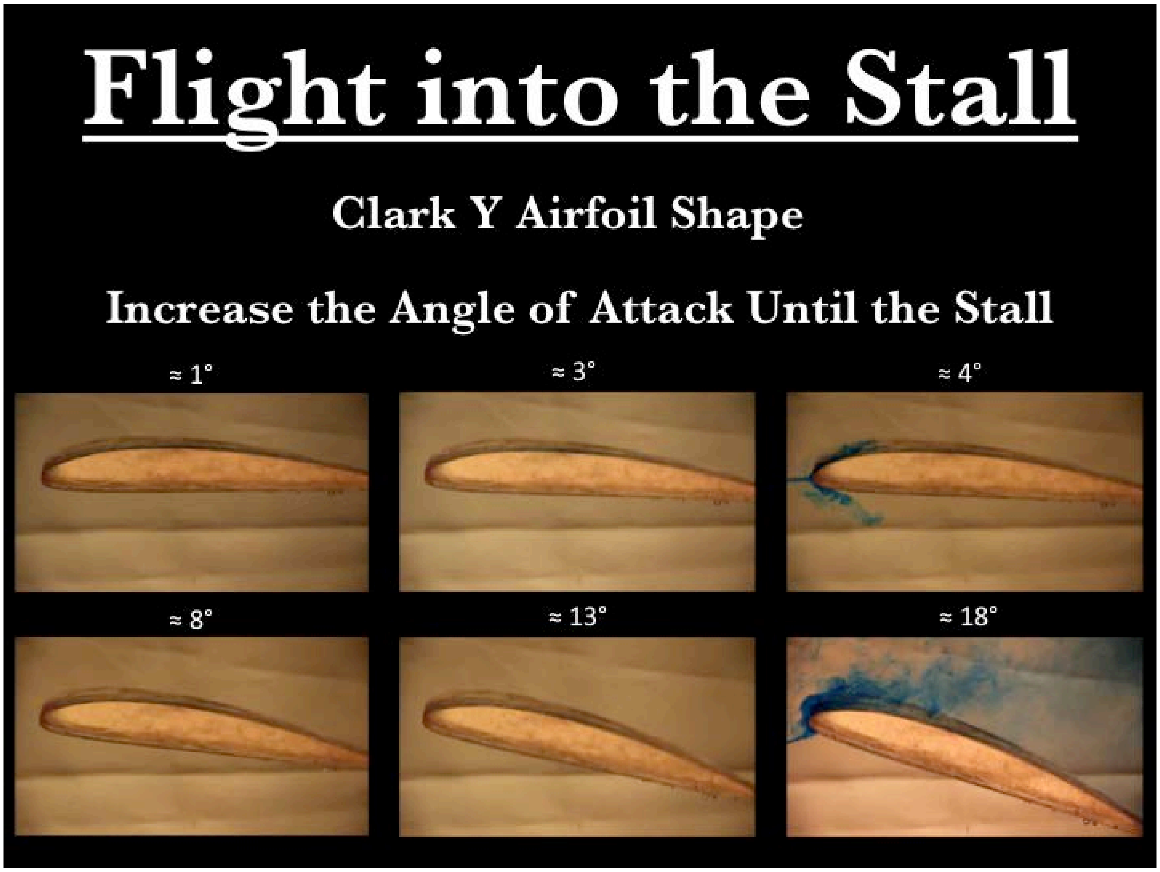

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Flow Visualization

MCEN 4047

Team Poject 1

March 14th, 2013

Introduction

I have always been entranced by flight. Recently I have been taking flying lessons, and I have been learning the basic physics of flight. I have been able to both learn about lift, angle of attack, and stalls and experience these topics that I have learned when flying in the aircraft. Because of this I became interested in being able to see how fluid acts as it moves over the wing of my aircraft. In my Flow Visualization course at the University of Colorado my team decided to work in the flume in the Integrated Teaching and Learning Laboratory (ITLL). My team members, whom helped me with the experiment, are Alex Meyer, Shweta Maurya, and Jeff Pilkington. I wanted to visualize fluid flow over a wing and how that flow changes as the angle of attack is increased until the stall point. Kiah Smith helped me create the video, and Ben Jones and Colonel Jim Voss helped in explaining the aerodynamics to me.

Flow Apparatus and Physics

We utilized the flume in the ITLL to visualize the flow over the airfoil. We fixed an IV bag full of blue dye above the flume and attached a needle to the end of the IV tube. The flow direction is shown in Figure 1, and the needle was placed an inch or closer in front of the airfoil. We designed the airfoil so that it would press fit in between the flume walls and hold itself at any orientation we placed it at.

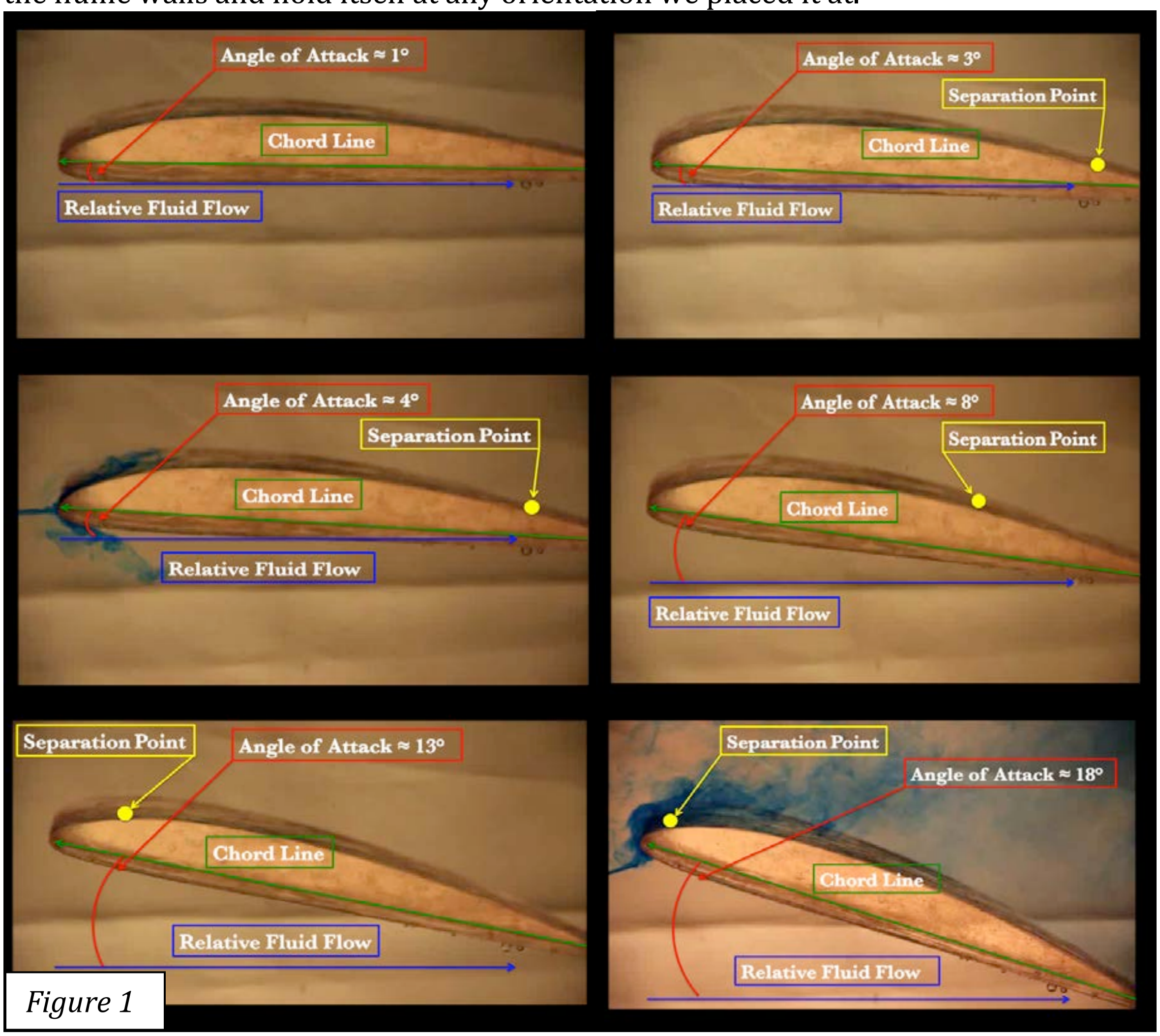

Figure 1

In order to create the airfoil we used a Solidworks rendering of a Clark Y airfoil that we found online at GrabCAD.com.[1] We printed the profile of the Clark Y airfoil thirteen times in the laser cutter, which cut out thirteen of the same shape that we glued together to make our final three dimensional part. We placed the airfoil at six different angles of attack which are shown in Figure 1. The angle of attack is the difference between the chord line (line through the center of the wing) and the relative fluid flow. Each angle of attack revealed a different fluid flow path over the wing. We placed a weir in the flow in order to slow it down enough so that we could see the dye interact with the airfoil.

"An airfoil is any surface, such as a wing, which provides aerodynamic force when it interacts with a moving stream of air."[2] Lift generated by a cambered airfoil is a very complicated process that is caused by a combination of several different factors. I will do my best to explain lift, and I will relate it to the fluid physics that can be seen in my video. The first physical phenomenon that causes lift can be described by Bernoulli's principle, which inversely relates velocity and pressure. The airfoil is cambered (curved more on the top) and therefore the fluid has a longer distance to travel as it moves over the top of the wing than it does on the bottom. In order to travel this distance in the same amount of time as on the bottom, the fluid on top of the wing must travel faster than the fluid on the bottom of the wing. According to Bernoulli, because the velocity of the fluid is higher on the upper portion of the wing the pressure will be lower. This relatively high pressure on the bottom of the wing and relatively low pressure on the top of the wing creates lift. This phenomenon can clearly be seen in both the three and four degree angle of attack configurations: the velocity on top of the wing is clearly greater than that on the bottom. As the angle of attack is increased the distance that the fluid must travel becomes relatively longer on top than on bottom so the speed increases on the top and decreases on the bottom and causes more lift with an increasing angle of attack. Unfortunately the separation point moves forward on the airfoil which will eventually cause a decrease in lift, otherwise known as a stall, but this will be discussed later. (Entire paragraph)[2,5]

The airfoil deflects the air both down and backward. As the angle of attack increases, the airfoil deflects the air at a steeper downward angle. According to Newton's third law of motion, "for every action there is an equal and opposite reaction."[2] As the air is forced at a steeper angle down, the opposite reaction to that action is that the airfoil will create more lift. This is harder to visualize in my video, but as you move from a four to an eight degree angle of attack you can see that the dye is deflected at a steeper downward angle. Also, Newton's third law applies at the front of the airfoil as the fluid strikes the bottom of the airfoil and it is deflected downward. The opposite reaction to this is a force pushing the airfoil upward. This can be seen well in the eight degree angle of attack and at the end of the video of the thirteen degree angle of attack. (Entire paragraph)[2,5]

Stalls occur when the airfoil's lift stops increasing and starts decreasing. Stalls can be very dangerous during flight, depending on when and where they occur, because of the sudden decrease in the amount of lift the airfoil is producing. Stalls are caused by the separation of fluid from the top of the airfoil. The separation point is spot on the airfoil where the fluid separates from the airfoil. This separation point occurs due to the flow's inability to change its direction quickly enough and overcome its momentum. As the angle of attack increases the amount of change in direction that the fluid must undergo also increases. Because of this the separation point moves further up the wing as the angle of attack increases; this can be seen in the video, where I have pointed out the separation point in yellow. The separation point marks the point at which the flow is separated past that spot. Separated flow does not create lift; the flow is not attached, swirling, and at zero or negative velocity within the boundary layer on the airfoil. This flow no longer produces the pressure gradient of low pressure on top of the wing and high pressure on the bottom of the wing. Therefore, the portion of the airfoil behind the separation point is no longer creating lift according to Bernoulli's principle. When this separation point moves far enough forward the airfoil's lift will begin to decrease, and at that point the airfoil has stalled. (Entire paragraph)[2,5,6]

The Clark Y airfoil stalls somewhere between a ten and fifteen degree angle of attack as can be seen in the appendix Figure A-2. For this reason the thirteen degree angle of attack in the video can be considered the beginning of the stall, and the eighteen degree angle of attack can be considered fully stalled. The data in Figure A-2 uses much higher Reynolds's numbers than we were able to obtain in our visualization. The Reynolds's number (Re) in the video can be calculated from the fluid velocity of V=0.74821 ft/s (0.5101 mph), a kinematic viscosity (ν) for water of 1.052*10^-5 ft^2/s, and a chord length of c=0.5625 ft.[3,4]

$$Re = \frac{Vc}{\nu} = \frac{\left(0.74821 \, {ft}/{s}\right) * (0.5625 \, ft)}{(1.052 * 10^{-5} \, {ft^2}/{s})} \approx 40{,}000$$

Equation 1[3,4]

This corresponds to laminar flow, as turbulent flow starts at 5*10^5 in an open channel.[3]

Visualization Technique

In order to visualize the flow over the wing we injected water and blue cake-icing dye mixture from a medical IV bag into the flow via an eight-inch needle. We fixed the IV bag above the flume as seen in the appendix in Figure A-1. We used two yellow construction lights (500 W Tungsten Bulbs) that were both placed approximately two feet behind and slightly below the flume. These lights were pointed at and shined through a white fabric sheet in order to soften the light and create a bright and constant backdrop to visualize the dye moving past the airfoil. The other lights in the immediate area were turned off, but there was still a small amount of ambient light (enough to clearly see and walk around).

Film Technique
The field of view is six inches in the horizontal direction and three and one-half inches in the vertical direction. We chose this field of view so that we could get as close as possible to the airfoil while still being able to see what was happening to the flow; we wanted to see as much detail as possible while still keeping most of the airfoil in the image. The lens of the camera was approximately two feet from the airfoil. The video was taken with a digital Canon EOS 60D DSLR camera using an EF-S 18-135 zoom lens. The height of the video is 5184 pixels and the width of the video is 3456 pixels. The focal length was 135 millimeters. The aperture was set to f/6.3 and the ISO was 2500. The ISO allowed enough of the light coming from behind the sheet to produce a clear and well defined movie at 60 frames per second. I then, with the help of Kiah Smith[7], took six different video clips and put them together in order of smallest to largest angle of attack. I also used PowerPoint to create the intro image with the overview of the six angles of attack, the image before each video showing the angle of attack and separation point, and the credits at the end.

Conclusion
The video reveals both a visual of how fluid moves over an airfoil creating lift, and how that movement changes with an increasing angle of attack. I have read about lift and stalls in books and seen drawings representing what is happening, but I wanted to create a video that could teach both me and others through a visualization of what is actually happening as the wing's angle of attack gets closer to the critical angle of attack and the stall. If I made the video again I would like to show more angles of attack, particularly between eight and thirteen degrees because the separation point moves quite a bit during that time. The physics of flow which causes lift are shown quite well, but, again, I would like to see angles of attack every two degrees from zero to sixteen degrees. I absolutely fulfilled my intent and I was very pleased in being able to see the interactions between the fluid and the airfoil that I expected. I enjoyed getting to learn more about the fluid forces of lift and see this fluid in motion during our experiment.

Appendix

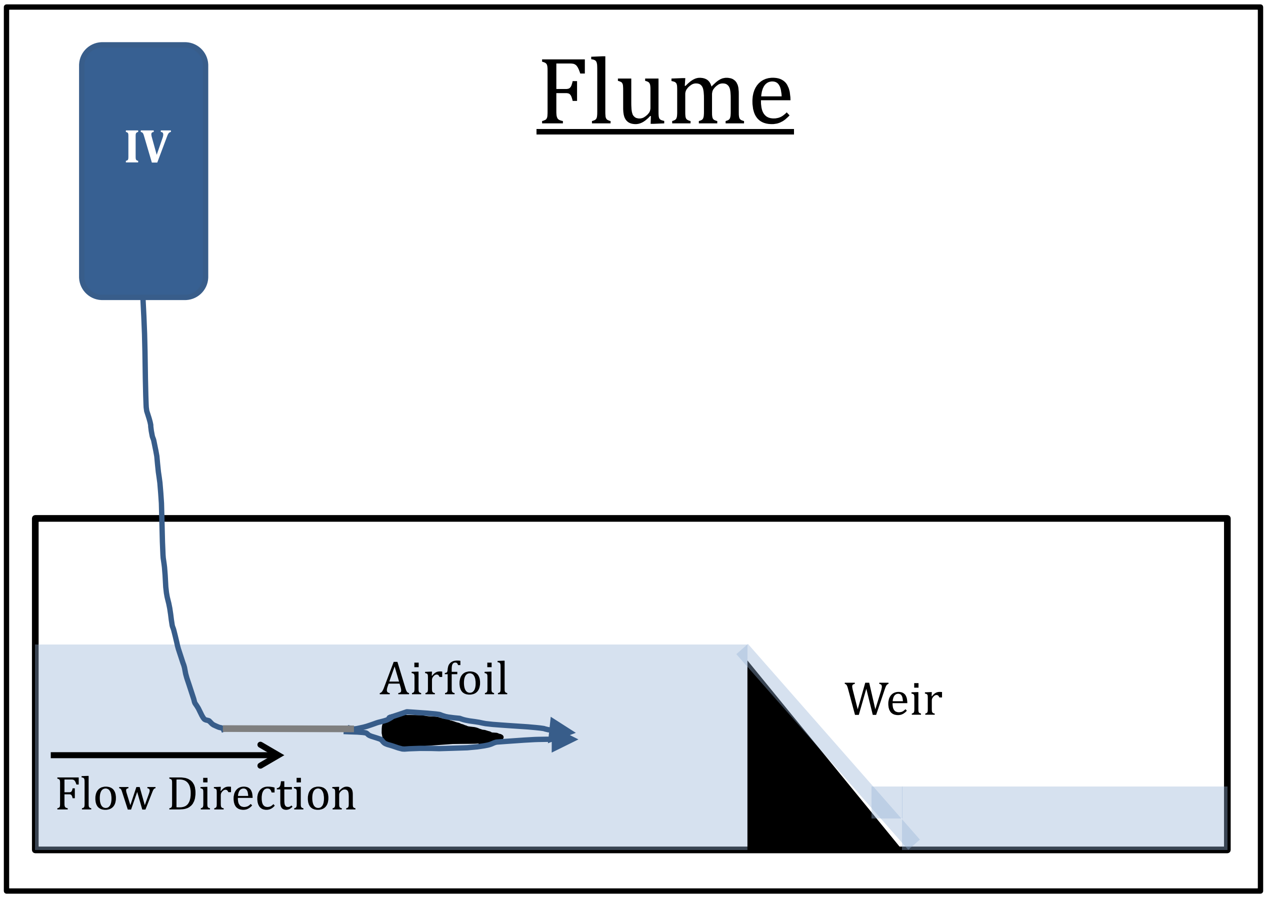

Figure A-1

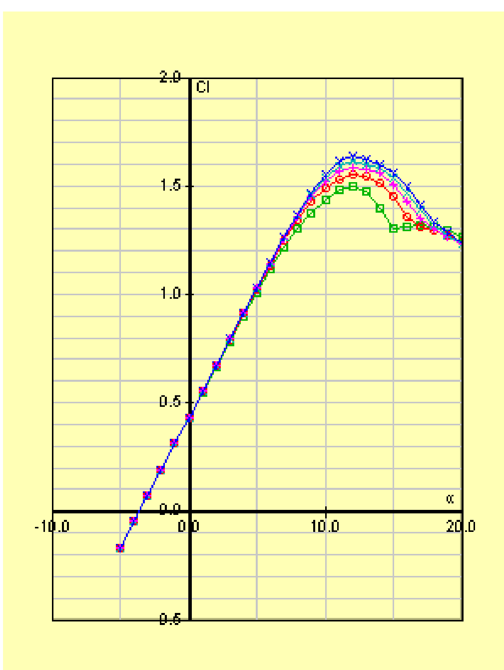

Figure A-2[8]

References:

[1] Nelson, David. "Aerofoil (Clark Y)." *GrabCAD*. GrabCAD, 21 Feb. 2013. Web. 3 Mar. 2013.

[2] "Chapter 3 Section A: Four Forces of Flight." *Guided Flight Discovery.* Englewood, CO: Jeppesen Sanderson, 2006. N. pag. Print.

[3] "Reynolds Number." *Wikipedia*. Wikimedia Foundation, 03 Oct. 2013. Web. 15 Mar. 2013.

[4] "Water - Dynamic and Kinematic Viscosity." *Water - Dynamic and Kinematic Viscosity*. N.p., n.d. Web. 15 Mar. 2013.

[5] Jones, Ben. Personal Interviews. January-March 2013.

[6] Voss, Jim. Personal Interview. March 7, 2013.

[7] Smith, Kiah. Video Help. March 6, 2013.

[8] "Clark Y Characteristics." *Clark Y Characteristics*. N.p., n.d. Web. 15 Mar. 2013. <http://library.propdesigner.co.uk/html/clark_y_characteristics.html>.